EVALUATION OF VARIOUS LONGITUDINAL JOINT CONSTRUCTION TECHNIQUES FOR ASPHALT AIRFIELD PAVEMENTS

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ABSTRACT

A longitudinal construction joint occurs when a lane of Hot Mix Asphalt (HMA) is constructed adjacent to previously placed HMA. The premature deterioration of the longitudinal joint occurs in the form of cracking and/or raveling. The distresses are caused by relatively low density and surface irregularity at the joints. A study on longitudinal joints on asphalt airfield pavements, funded by the Airfield Asphalt Pavement Technology Program (AAPTP) is currently underway. The scope of work consists of literature review, survey of users, recommendations of changes in specifications and the development of a manual on best practice. It is preferable to produce hot longitudinal joints by operating two or more pavers in echelon. But in a majority of cases, echelon paving is not possible especially with limited capacity of HMA production to feed more than one paver. However, attempt should be made to pave in echelon at least the central portions of runways and taxiways. This would minimize the number of longitudinal joints in the area, which is subjected to direct application of severe aircraft loadings. If echelon paving is not possible then it is recommended to use the following best practices in order of preference for constructing durable longitudinal joints. 1. Combination of Notched Wedge Joint, Rubberized Asphalt Tack Coat, and Minimum Joint Density; 2. Rubberized Asphalt Tack Coat and Minimum Joint Density Requirements; 3. Notched Wedge Joint and Minimum Joint Density Requirements; 4. Cutting Wheel and Minimum Joint Density Requirements.

INTRODUCTION

A longitudinal construction joint occurs when a lane of Hot Mix Asphalt (HMA) is constructed adjacent to previously placed HMA. Longitudinal joints are inevitable in both highway and airfield pavement, unless paving is done in the echelon formation (which is generally not the case). HMA pavements in airfields are designed and constructed to resist a host of distress conditions; however, unlike highways, airfield pavements do not have the beneficial effects of kneading effect from traffic. Therefore, along with the requirements for withstanding heavier loads, stripping and resisting ingress of water, airfield pavement HMA mixtures (mixes) have the additional requirements of resisting oxidation, related aging and raveling [1]. Furthermore, the pavements need to be constructed within relatively short periods of time, in many cases at nights, and hence workability is a primary concern.

Damaged longitudinal joints are of very serious concern in airfield pavements. Loose materials from such areas can cause Foreign Object Damage (FOD) to aircrafts, leading to loss of life and equipment. Potential sharp edges along open longitudinal joints can also endanger aircraft [2]. In addition, such joints (in airfield as well as highway pavements) can lead to ingress of moisture and undesirable materials and lead to premature failures in subsurface and ultimately entire pavement, leading to a cycle of costly and time consuming repairs.

For the above reasons, engineers, consultants and contractors have continuously tried to develop methods for constructing better performing longitudinal joints in pavements. Such methods include overlapping and luting operations; different types of rolling patterns for compacting the joint; and the use of special joint construction techniques and equipment, such as cutting wheel, restrained edge device, notched wedge joint, and joint heaters. At the same time, many agencies have started using specifications that are written specifically for construction of better joints such as density requirements at joints.

SCOPE

A study on developing a best practice manual for improved performance of longitudinal joints on asphalt airfield pavements, funded by the Airfield Asphalt Pavement Technology Program (AAPTP) is currently underway. The objectives of this study are to evaluate various techniques of constructing longitudinal joints and recommend best practice(s) for the improved construction and performance of longitudinal joints on asphalt airfield pavements. This paper summarizes the results of work conducted so far in this study. It presents the results of a review of literature and existing specifications, a survey of airport engineers across the country and recommendations on best practices.

LITERATURE REVIEW

The premature deterioration of the longitudinal joint occurs in the form of cracking and/or raveling. The distresses are caused by relatively low density and surface irregularity at the joints. A density gradient exists across a typical longitudinal joint. Such a density gradient is caused by the low density at the unconfined edge when the first lane (hereinafter called the cold lane) is paved and a relativity high density at the confined edge, when the adjacent lane (hereinafter called the hot lane) is paved. In addition, there is more rapid cooling of the HMA mix near the unconfined edge of the cold lane resulting in relatively low density. Therefore, it is not uncommon to encounter densities at the joint, which are significantly lower than those in the mat away from the joint [3, 4, 5, 6]. Burati and Elzoghbi [5] studied joint densities during 1984 construction of two Federal Aviation Administration (FAA) Eastern Region airports at Morristown Municipal Airport, New Jersey and Rochester-Monroe County Airport, New York. Joint core densities were significantly lower than mat core densities at both airports. Field evaluation of 35 highway pavements in Texas [6] revealed that the density was always lower at the unconfined edge than in the middle of the lane and this was almost always statistically significant. Similar experience has been documented on airfield runways [7].

Typically, a crack develops at the longitudinal joint in due course of time, sometimes as soon as one year in service (Figure 1). The crack becomes wider and more ragged every year. This phenomenon is more prevalent and severe in areas with very cold climatic conditions, which also cause transverse shrinkage cracking in HMA pavements. It is also not uncommon for the HMA pavement to develop raveling on one side of the longitudinal joint. In a majority of cases, raveling occurs on the side of the cold lane, which usually has lower density at the unconfined edge. Raveling can also occur on the side of the hot lane due to inadequate compaction, which may result from bridging action if the edge of the cold lane is higher than the hot lane due to excessive material. Both cracking and raveling allow intrusion of water into the pavement system, which weakens the foundation of the pavement requiring extensive repairs. Sealing of the longitudinal crack and patching of raveled areas also entail undesirable maintenance cost. Longitudinal joints often look coarse in surface texture. This can happen primarily for two reasons: segregation and handwork. Because longitudinal joints occur at the edge of the paver screed and auger system and the HMA has been moved beyond the end of the auger there is a potential of HMA being segregated. Typically, HMA from the hot lane, which overlaps the cold lane, is luted back onto the hot side of the joint. This handwork usually results in a coarse surface texture.

Reasonably good joints can be achieved under the following circumstances: 1. Good construction practices are followed, 2. Adequate compaction is achieved at the joint, 3. The pavement is not subjected to very cold climatic conditions, and 4. Highly temperature-susceptible asphalt binder, which may cause low temperature thermal cracking, is not used to produce HMA [8].

Figure 1. Typical Crack and Progression of Crack Along Longitudinal Joint

However, special longitudinal joint construction techniques have been used under the following circumstances to ensure improved performance:

1. Longitudinal joint has to be warranted for durability (no cracking or raveling);

2. As an aid to improve the density of the unconfined edge of the first paved lane, quite often in order to meet an agency's specified minimum density requirements at the joints;

3. To provide a built-in sealer at the joint to prevent ingress of water or dirt in case the longitudinal joint opens during pavement's service life.

Construction techniques

Longitudinal joints can be broadly classified as follows (3, 9):

1. **Hot Joints:** Hot joints are produced when two or more pavers are operating in echelon (parallel). The pavers are spaced closely such that the lane placed first does not cool significantly before the second lane is placed adjacent to the first lane. When the longitudinal joint is compacted, the HMA on both sides of the joint is essentially within the specified compaction temperature range and, therefore, a hot joint is produced. Constructed properly, a hot longitudinal joint appears almost seamless and produces the highest density when compared to semi-hot and cold joints [3]. On some Maryland highway projects it was determined that the average density of hot joints was about the same as the average density of the mat away from the joint [10]. But in a majority of cases, echelon paving is not possible because of today's constricted work zones especially in case of highways and limited capacity of HMA production to feed more than one paver. However, attempt should be made to pave in echelon at least the central portions of runways and taxiways. This would minimize the number of longitudinal joints in the area, which is subjected to direct application of severe aircraft loadings [11].

2. **Semi-Hot Joints:** A semi-hot joint or a warm joint is produced when the paver is restricted to proceed for a certain distance before moving back to place the adjacent lane. The HMA in the first lane generally cools down to a temperature of about 120^{o}F to 140^{o}F (49^{o} to 60^{o}C) before the adjacent lane is placed. Semi-hot joint is by far the most commonly used joint type on HMA paving projects. Numerous highway studies and an airfield study [4] have demonstrated that the semi-hot joint densities are significantly lower than the mat interior densities.

3. **Cold Joints**: A cold joint is produced when the first paved lane has cooled overnight or more before the adjacent lane is placed to match it. A cold joint will also be produced if paving of the first lane is carried too far ahead such that the HMA has cooled well below 120^{o}F (49^{o}C). Construction of durable longitudinal joints is an art, which requires a team of skilled people with paving experience [12]. The team primarily consists of the paving foreman, paver operator, raker or screed man, and roller operator. The team should follow good construction practices, which are presented here. Many of these construction practices have been reported by Schrocman [13] based on experience.

Paving and Compacting the First Lane: One of the most important requirements in obtaining a good longitudinal joint is that the paver operator should place the first lane in a uniform, unwavering line. Attention to this detail will simplify the placement of the adjacent lane with a uniform overlap. Another important requirement in obtaining a durable joint is proper compaction of the unsupported edge of the first lane (cold lane). The unsupported edge typically has a slope of approximately 60 degrees. Obviously, the wedge formed by this slope at the edge does not receive as much compaction as the mainline away from the edge [13]. Breakdown compaction with a vibratory or static steel wheel roller can be done with the roller operating in three different locations in respect to the unsupported edge of the first lane. First, rolling can begin with the edge of the roller drum away from the unsupported edge. However, this practice will cause the HMA to shove or move out due to shear loading on the mix at the edge of the steel drum. The extent of this transverse movement will depend upon the stiffness of the HMA mixture. This movement will (a) typically cause a crack to be formed at the edge of the drum, and (b) create a depression at the unsupported edge so that it will be very difficult to match the joint when the adjacent lane is placed [13].

Second, rolling can begin with the edge of the steel drum right on the unsupported edge of the first lane. Although this practice will eliminate cracking at the edge of the roller drum, it would still shove and push out the mix underneath the drum. Therefore, it would not be possible to obtain adequate density at the unsupported edge [13]. Third, rolling can begin with the edge of the steel drum extending over the edge of the first lane by about 6 inches (150 mm). At this position, the edge of the drum does not exert any shear force in the HMA because it is out hanging in the air. Therefore, there is minimal transverse movement of the HMA and reasonable amount of density is obtained at the unsupported edge of the lane. Obviously, this third practice of compacting the unsupported edge will produce the best results and is, therefore, recommended [13]. Pneumatic tired rollers are typically used in the intermediate phase of HMA compaction. However, they are sometimes used for breakdown rolling. In that case, pneumatic tired rollers do not perform as well as steel wheel rollers in constructing longitudinal joints. During rolling, the outer tire tends to roll over the unsupported edge of the first paved lane, which complicates the make-up of the joint when the adjacent lane is placed and compacted [13].

Paving the Second Lane and Overlapping: It is important to control the height of the uncompacted HMA in the hot lane. The height of the uncompacted HMA should be about 1¼ inch (32 mm) for each one inch (25 mm) of the compacted lift thickness in the cold lane. For example, if the compacted HMA in the cold lane is two inches (51 mm) thick, the height of the uncompacted HMA in the hot lane should be 2½ inches (64 mm), which is ½ inch (13 mm) above the level of the compacted mat [13]. Another key point in obtaining a good longitudinal joint is proper overlapping during the paving operation. The end gate of the paver should extend over the top surface of the previously placed HMA by a distance of approximately 1 to 1½ inches (25 to 38 mm). Attention to this detail will not only provide the requisite amount of HMA on top of the joint for proper compaction, it will require minimal or no raking and luting [13, 14]. If the overlap is consistent and within this suggested range, it will be better to avoid raking or luting altogether. Sometimes, an existing HMA is milled in one lane and a new HMA lift is placed as an inlay. In this case, the edge of the old, compacted HMA is almost vertical due to milling operation unlike the slope or wedge typically formed by the edger plate on the paver screed. In such cases, the amount of overlap should be no more than about ½ in (13 mm) to obtain a good longitudinal joint [13].

Raking and Luting: Raking or luting at the longitudinal joint can be eliminated if the minimal overlapping as recommended previously is followed. An excessive overlap will require removal of extra material from the cold lane onto the hot lane otherwise the aggregate in the mix remaining on the compacted lane will get crushed resulting in raveling. When that happens, the excessive overlapped material on the cold lane may be "bumped" with a lute onto the hot mat **just** across the joint. The bump should lie just above the natural slope or the wedge at the edge of the cold lane. Since the HMA on the slope is usually not adequately compacted, there is a good potential that the roller can crowd and compact the bump into the joint.

Quite often, the person doing the raking sets the rake down on the compacted mix of cold lane and push the overlapped material farther across the joint on top of the uncompacted HMA in the hot lane. Due to this improper raking, the mix essentially remains at the same elevation on both sides of the joint and too high on the hot lane a short distance away from the joint. The problem is that the mix on the cold side of the joint is compacted and the mix on the hot side of the joint is uncompacted. Unless the loose HMA on the hot side is high–about ¼ inch (6 mm) higher for each one inch (25 mm) of compacted thickness–it is not possible for the roller to compact this mix adequately resulting in very low density. Moreover, the higher elevation of the loose HMA on the hot lane a short distance away also causes roller drum to bridge on the mat on the hot side of the joint, further contributing to low density. This undesirable construction practice creates two problems. First, the HMA adjacent to the joint toward the hot lane starts to ravel under traffic due to inadequate compaction (high air voids), which also allows intrusion of water into the pavement. Second, the HMA surface adjacent to the joint toward the hot lane is depressed and, therefore, ponding of rainwater will occur, which will deteriorate the joint [13].

Sometimes, there is a tendency to broadcast the raked material onto the HMA in the hot lane. This is not only undesirable for obtaining a good longitudinal joint but it also affects the surface texture of the mat adversely.

Compacting the Longitudinal Joint: Obtaining adequate compaction at the joint is the final key in obtaining a durable longitudinal joint. Extensive field research by the National Center for Asphalt Technology (NCAT), discussed later, indicated that the joints with high densities generally showed better performance than those with relatively low densities [15, 16].

Most specifications for longitudinal joint density require the density level at no more than 2 percent below the required mainline mat density. By paying attention to construction details mentioned earlier, it is possible to obtain a joint density within 1.5 percent of the mainline density [13].

Usually, it is not possible to obtain an accurate density measurement right on the joint using a nuclear gauge, which is centered on top of the visible line between the cold and hot lanes. This is because the nuclear gauge cannot be placed flat across the joint without rocking [16]. The compacted HMA on one side of the joint is usually higher than the other side causing uneven surface across the joint. Similarly, the nuclear gauge cannot be placed flat on a joint with a crown.

Therefore, the joint density is best measured by obtaining a 6 inch (150 mm) diameter core centered on top of the visible line between the two lanes. It should be noted that the core would not consist of equal volumes of mix from the cold lane and the hot lane. Due to the presence of natural slope at the unconfined edge of the cold lane, most of the mix in the core will come from the cold lane. This is all right because the density of the cold side is of major concern.

Echelon Paving: Usually the pavers are within 30 feet (9 meters) of each other. The amount of overlap is critical in obtaining a durable hot joint. The end gate of the trailing paver should not extend more than one inch (25 mm) onto the adjacent HMA placed by the leading paver. This will prevent the end gate of the screed of the trailing paver from dragging on the HMA already placed by the leading paver. Careful attention to this overlap will not require any raking either, which is difficult to do by standing on the uncompacted mat of the first lane [14].

Breakdown roller that is compacting the HMA behind the leading paver should be kept at least 6 inches (150 mm) away from the edge of the mat. After the trailing paver places HMA against the uncompacted edge of the first lane, the rollers that are working behind the trailing paver are used to compact the HMA on both sides of the joint. If the above procedures of proper overlap and compaction are followed, a virtually seamless pavement can be obtained [14].

Tack Coating Longitudinal Joints: According to some engineers, applying a tack coat on the face of the unconfined edge of the cold lane ensures a better bond (adhesion) and seal of abutting HMA lanes. The tack coat usually consists of asphalt cement, emulsion, or hot poured, rubberized asphalt sealer. Application of tack coat is a standard practice in some countries, for example, United Kingdom, Japan, and South Africa. However, opinions vary in the United States. Some engineers believe application of thin tack coating material such as asphalt cement and emulsion in case of semi-hot joint is unnecessary since it may not contribute in improving the durability of the longitudinal joint [14]. Recent NCAT field research, discussed later, has demonstrated that the use of hot-poured, rubberized asphalt sealer as a tack coat (about 1/8 inch or 3 mm thick) on the face of the first paved lane produced the most durable longitudinal joints. Therefore, it appears that thick tack coats may be more effective than generally used thin coats of asphalt cement or emulsion.

NCAT initiated a national study of evaluating various longitudinal joint construction techniques in 1992 with the cooperation of the state departments of transportation and the HMA industry. This study [15, 16, 17] involved evaluation of 12 different construction techniques used on four projects: (a) seven techniques on I-69 in Michigan (1992); eight techniques on State Route 190 in Wisconsin (1992); seven techniques on I-25 in Colorado (1994); and eight techniques on State Route 441 in Pennsylvania (1995). Each test section within a project was 500 feet (152 m) long. Different joint construction techniques also included three joint rolling techniques described earlier. Unless otherwise indicated, rolling of all other test sections was done from the hot side. Brief descriptions of the techniques are given below.

Notched Wedge Joint: The notched wedge joint is formed by providing a vertical notch and a taper at the edge of the lane paved first (cold lane). A taper of 1:12 (vertical: horizontal) was used. The taper is then overlapped when the adjacent lane (hot lane) is placed (Figure 2).

Edge Restraining Device: The restrained edge compaction technique utilizes an edge-compacting device, which provides restraint at the edge of the first lane constructed. The restraining device consists of a hydraulically powered wheel, which rolls alongside the compactors drum simultaneously pinching the unconfined edge of the first lane towards the drum providing lateral resistance [14]. This technique is believed to increase the density of the unconfined edge. The adjacent lane is then abutted against the initial lane edge.

Cutting Wheel: The cutting wheel technique involves cutting 1½-2 inches (38-51 mm) of the unconfined, low-density edge of the first lane after compaction, while the mix is still plastic. A 10-inch (254-mm) diameter cutting wheel mounted on an intermediate roller is generally used for the purpose [14] (Figure 3). The cutting wheel can also be mounted on a motor grader, which was the case in Michigan and Colorado. This process obtains a reasonably vertical face at the edge, which is then tack coated before the placement of the abutting HMA.

Joint Maker: This is an automated joint construction technique developed in the early 1990s. It consists of a device, which is attached to the side of the screed at the corner during construction. The device forces extra material at the joint through an extrusion process prior to the screed. It is claimed that proper use of the joint maker ensures high density and better interlocking of aggregates at the joint.

Tapered (1:3) Joint with Vertical One-Inch Offset: In this method used in Colorado, the unconfined edge of the 2-inch (51 mm) thick cold lane was constructed with a 1-inch (25 mm) vertical step (offset) at the top of the joint and a 1:3 (1 vertical: 3 horizontal) taper starting from the base of the vertical step.

Rubberized Asphalt Tack Coat: The unconfined edge of the first paved lane adjacent to the joint was not provided with any taper in this experimental section. On the following day, a rubberized asphalt tack coat (Crafco pavement joint adhesive Part Number 34524) was applied on the face of the unconfined edge before placing the adjacent lane (Figure 4). The thickness of the tack coat was about 1/8 inch (3 mm).

New Jersey Wedge (1:3): In this technique used on the Pennsylvania project, a wedge joint consisting of a 1:3 (1 vertical: 3 horizontal) taper was formed during construction of the first lane by using a sloping steel plate attached to the inside corner of the paver screed extension [18]. During the second pass of the paver an infrared heater was used to heat the edge of the previously placed layer to a surface temperature of about 200 deg.F (93 deg. C).

Construction details of all four projects have been published elsewhere [15, 16, 17]. Periodical and final performance evaluation data for all four projects has been published during the 1994-2002 period [15, 16, 17]. The following general conclusions were drawn from this extensive NCAT research project:

1. Longitudinal joint constructed with rubberized asphalt tack coat (joint adhesive) gave the best performance with no significant cracking. The joint was hardly visible;

2. The notched wedge joint with 1:12 taper has the best potential of obtaining a satisfactory longitudinal joint;

3. Both cutting wheel and the edge-restraining device have a good potential of obtaining a satisfactory joint. However, these techniques are operator dependent and, therefore, may not give consistent performance results. For example, the quality of joint with cutting wheel is dependent upon the skill of the operator in making a straight cut and the skill of the paver operator in matching the cut edge if it is not straight or it is wavering;

4. Rolling of the longitudinal joint should be done from the hot side with 6-inch (150 mm) overlap of the roller drum on the cold lane. Rolling should preferably be done with a vibratory roller as soon as possible to obtain the highest possible density of the joint to ensure best performance;

5. Joints with high densities generally showed better performance than those with relatively low densities. Therefore, the user agencies should specify minimum acceptable compaction levels to be achieved at the joint. It is recommended that the density at the joint be not more than

two percent lower than the density specified in the lanes away from the joint. Densities right on the visible joint line need to be determined by taking cores. It is not possible to use nuclear density gauge because of seating problem right on the joint.

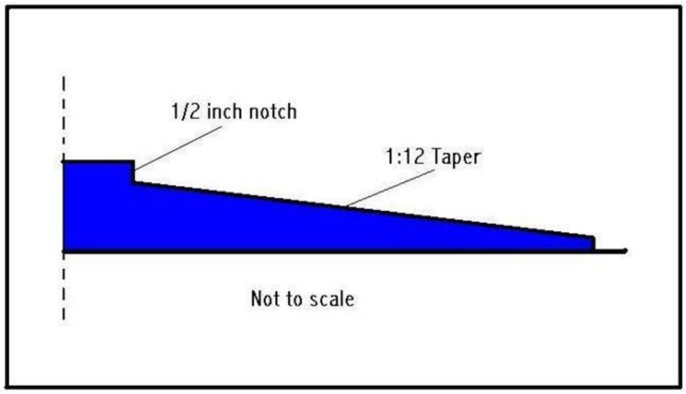

Figure 2. Schematic of Notched Wedge Joint.

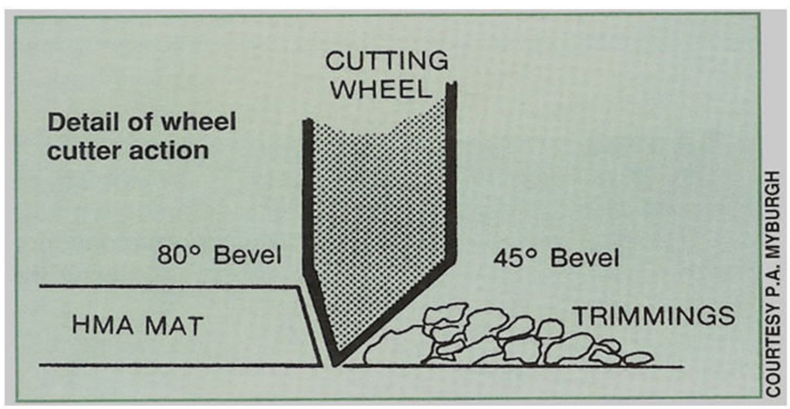

Figure 3. Schematic of Cutting Wheel.

Figure 4. Application of Rubberized Asphalt Tack Coat on Edge of Lane.

Beside the NCAT study, another comprehensive longitudinal joint study [19] was undertaken by the Kentucky Transportation Center in 1999 to evaluate joint density produced by different techniques. Some of the major conclusions and recommendations from this study include:

1. Contractors are consistently achieving levels of density at or near the construction joint that are within three percent of the lane density. It is recommended that specifications be written that would require contractors to achieve that level of density at or near the construction joint;

2. The infrared joint heating system achieved the highest joint density of all the methods; however, only one short project was included in this study. The restrained-edge method of joint construction achieved the second highest overall densities and statistically was significantly better than the conventional method of joint construction. The notched wedge only marginally improved densities overall, while the joint maker showed no improvement over conventional construction techniques;

3. It appeared the notched-wedge joint method produced the lowest permeabilities at the joint;

4. Preliminary performance data indicate that all projects are currently performing well with projects having joint adhesives performing as well as, or better than, projects without joint adhesives. It is recommended that more projects be constructed using joint adhesives.

Another comprehensive study [20] was undertaken by the Wisconsin Department of Transportation in 1993. The performance of eight joint construction techniques including cutting wheel and edge restraining device with emphasis on the notched wedge joint was evaluated for 10 years. Various techniques of compacting the notched wedge joint were evaluated. Performance evaluations were based on density results and an overall performance ranking based on amount of longitudinal joint cracking. The following conclusions were drawn and recommendations made:

1. The notched wedge joint performed better than the cutting wheel and restrained edge joint. The results show that the notched wedge joint in Wisconsin, when constructed with better equipment and by more experienced workers, performs as well as it does in Michigan;

2. From the constructability standpoint, the notched wedge joint creates less debris and can be constructed more efficiently than the cutting wheel joint and the restrained edge joint. The results of this study have found that the tag-along roller and the steel wheel side roller compaction techniques both produce acceptable wedge joints.

Specifications: Burati and Elzoghbi [5] evaluated the 1984 construction of two FAA Eastern Region airports in Morristown, New Jersey and Rochester, New York. Rochester airport was constructed without a pay adjustment provision in its specification for joint construction. The specifications for the Morristown airport included pay adjustments for joint density. Joint density variability was significantly higher than the adjacent mat density variability at Rochester but not at Morristown. Both projects were constructed with density differences between joint and mat areas of 6 to 7 lbs per cu ft (96 to 112 kg per cu m). The average density ratio (joint/mat) ranged from 95 to 96 percent. The Burati-Elzoghby study was instrumental in the FAA’s use of joint density in acceptance of asphalt airfield pavement construction. The P-401 Specification dated July 7, 1992 included basic acceptance criteria developed in their study. According to a study in 1991 [21] increased emphasis on joint density through a proper HMA specification with financial incentives does produce improved test results. Joint density was specified at 96.5 percent minimum of Marshall laboratory density on several airfield HMA projects. On projects without any financial incentive 99.7 percent of the sampled joints did not meet the specification requirement.

The 10-year (1992-2002) NCAT field study on longitudinal joints [16, 17] concluded the following pertaining to joint density: Joints with high densities generally showed better performance than those with relatively low densities. Therefore, the user agencies should specify minimum acceptable compaction levels to be achieved at the joint. It is recommended that the density at the joint be not more than two percent lower than the density specified in the lanes away from the joint. Densities right on the visible joint line need to be determined by taking cores. It is not possible to use nuclear density gauge because of seating problem right on the joint. Sebaaly et al [22] evaluated various joint geometrics and rolling techniques in Nevada during 2004 and 2005 with an objective to develop a joint density specification for HMA projects. Based on the statistical analysis of extensive field data they recommended that the Nevada DOT implement the following joint density specification: The density at the joint should be a maximum of 2 percent less than the corresponding mat density and the density at the joint should be a minimum of 90 percent of the theoretical maximum density (TMD). The above specification requirement is in accordance with NCAT study's recommendations.

Sebaaly et al also concluded that all three joint geometrics studied by them, natural slope, cut edge with rubberized asphalt tack coat, and tapered (3:1) joint will meet the recommended joint density specification. Kandhal [23] asked the state highway agencies in 2004 as to what steps they have taken in recent years for obtaining a durable longitudinal joint. The state highway agencies are concerned with the durability of longitudinal joints and more and more are seriously considering specifying a minimum level of density at or near the joint.

The most recent Federal Aviation Administration's (FAA's) Advisory Circular (AC) 150/5370-10B Item P-401 Plant Mix Bituminous Pavements dated April 25, 2005 was reviewed in terms of joint density requirements [24]. Revision of the compaction levels need to be considered in view of the following:

1. Studies have shown that in surface courses density at the joint is achievable within 1.5 to 2 percent of the mat density. The present specification allows joint density to be 3.0% below the mat density, which appears liberal. Studies have generally shown that the higher the density at the joint, better is the performance of the joint;

2. According to the specification a joint density of 93.3% of the laboratory compacted specimens is allowable. Air void content of 2 to 5 percent is permitted in the laboratory compacted specimens. Air voids are calculated based on the theoretical maximum density (TMD) using ASTM D2041. In the worst-case scenario, a contractor can have 5% air voids in a laboratory compacted specimen that is 95% of TMD. Therefore, at the joint the allowable compaction can be as low as 93.3 x 95 or 88.6% of TMD, which amounts to 11.4% of air voids at the joints. Most state DOT specifications allow no more than 10% air voids at

the joint. Therefore, the FAA specification should be reviewed and probably made more stringent;

3. Consideration should also be given to make compaction level both at the joint and mat based on TMD rather than the bulk specific gravity of daily compacted Marshall specimen, which is more variable. Most state DOTs use TMD rather than bulk specific gravity of the compacted Marshall specimen. It is the air void content we are concerned rather than the percent compaction. In other words, the durability of the joint is related to air voids content rather than the percent compaction.

The latest Unified Facilities Guide Specifications [25] dated April 2006 was also reviewed in terms of joint density requirements. The following observations are made:

Unlike the FAA P-401 Specification, this specification specifies the minimum joint density based on the theoretical maximum density (TMD) rather than the density of the laboratory compacted Marshall specimen. As discussed earlier the use of TMD is preferable because it directly gives the air voids at the joint. Also, this specification requires a minimum average joint density of 92.5 percent based on the TMD to get 100 percent pay. That is, no more than 7.5 percent average air voids at the joint. The P-401 specification can permit air voids as much as 11.4 percent at the joint in the worst-case scenario as discussed earlier. Most state DOT specifications do not allow air voids at the joint exceeding 10 percent. Therefore, this United Facilities Guide Specification is more stringent and, if met, should produce a more durable joint compared to the FAA P-401 and most state DOT specifications. This specification requires a minimum average mat density of 94.0 percent of the TMD to get 100 percent pay. That means, the joint density cannot be more than 1.5 percent (94.0 – 92.5) lower than the mat density.

RESULTS OF SURVEY OF DIFFERENT AIRPORTS

A combined e-mail and phone survey of airport engineers/consultants in different parts of the country was conducted. Questions were asked regarding their experience with different types of longitudinal joint construction techniques. Airports surveyed included those in Boston, MA, New York, NY, Omaha, NE, Dayton, OH, Fort Wayne-Allen County Airport, IN, Anchorage, AK, Burbank-Glendale Pasadena, CA and Salt Lake City, UT, as well as from Air Combat Command bases and LPA associates, SC. The following salient points concerning longitudinal joints were made by various airport engineers.

1. Typical distresses such as cracking and raveling in longitudinal joints happen in about four to five years after construction. Initially a crack occurs along the joint, which leads to secondary cracks. Generally, these cracks are sealed promptly by the maintenance crew before they become a problem. Hot poured rubberized asphalt is usually used for crack sealing. Raveled areas adjacent to joints are patched before they pose Foreign Object Damage (FOD);

2. Overdoing the luting operation can potentially cause segregation at or near longitudinal joint;

3. Paving in echelon may not always be practical since enough quantity of HMA may not be available to feed two pavers;

4. According to one agency, rolling from the cold side with a 12-inch overlap on the hot side provides a smoother transition between mats without any bump;

5. The skill and experience of screed operator, raker, and roller operator are probably the most vital component making a good longitudinal joint;

6. One agency requires the use of two pavers working in echelon in center sections of runways and taxiways. A material transfer vehicle (MTV) is also required for large airport projects;

7. Performance related specifications especially those related to joint density have helped in improving the quality of joints. Possibility of penalty due to low density at joint has forced contractors to use techniques such as cut back of cold joints to improve joint density;

8. Some agencies have reduced the nominal maximum aggregate size from ¾ inch to ½ inch to minimize segregation at joint as well as in the mat away from the joint;

9. One agency has a requirement of using a 25-feet wide paver;

10. Some agencies do not require cutting back, application of tack coat, and checking of density for the bottom lift joints;

11. Some agencies require 4 samples per lot for testing joint density. Cores are centered directly over the joint;

12. One agency requires the same compaction (minimum 98 percent of the laboratory density) for joint and the mat away from the joint;

13. Cutting back the pavement edge of the cold lane is probably the best method and works well to obtain high joint density.

CONCLUSIONS AND RECOMMENDATIONS ON BEST PRACTICE

It is preferable to produce hot longitudinal joints by operating two or more pavers in echelon. If echelon paving is not possible then it is recommended to use the following best practices for constructing durable longitudinal joints. These practices are listed in decreasing order of preference

1. Combination of Notched Wedge Joint, Rubberized Asphalt Tack Coat, and Minimum Joint Density Requirements.

Construct a notched wedge longitudinal joint. The unconfined edge of the first paved lane has a vertical notch at the edge generally ranging from ½ inch (13 mm) to 3/4 inch (19 mm) in height depending upon the nominal maximum aggregate size (NMAS) of the HMA mixture. Generally, a vertical notch of about ½ inch (13 mm) height is considered adequate for most surface course mixtures. The height of the notch can be increased in case of binder and base course mixtures, which have a larger NMAS. At the bottom of the vertical notch, the wedge is provided a taper of 1:12 (vertical: horizontal). To avoid feathering the taper to zero height, which may cause dragging of the HMA, it is recommended to end the taper with a minimal height such as 3/8 inch (9.5 mm) to avoid dragging of the material.

Usually a loaded wheel, which is attached to the paver, is used to compact the taper. Typically, the roller weighs 100 to 200 lbs (45 to 91 kg) and is approximately 14 inches (356 mm) wide by 12 inches (305 mm) in diameter. There is no need to compact the taper with a conventional steel or pneumatic tired roller because it will simply destroy the vertical notch. The overlap layer of the adjacent paving lane is required to be placed and compacted within 24 hours unless delayed by inclement weather. The vertical notch and taper are tack coated with rubberized asphalt binder prior to placing the overlap wedge as described later. The notched wedge joint can be formed by using a homemade sloping steel plate attached to the inside corner of the paver screed extension. However, commercial devices are now available which can be attached to the screed to form the notched wedge joint.

The notched wedge joint does not always work well for thinner HMA lifts. Ideally, it gives the best results with a minimum lift thickness of 1½ to 2 inches (37 to 51 mm). On the other hand, excessive thick lifts produce a long taper, which may not be desirable. In those cases, the length of the taper is generally restricted to 12 inches (305 mm). The top course taper shall overlap and slope in the opposite direction of the lower course taper. After the first lane (cold lane) is paved with a notched wedge and compacted, a rubberized asphalt tack coat (Crafco pavement joint adhesive Part Number 34524 or equivalent) is applied on the face of the unconfined edge of the cold lane. The thickness of the tack coat is about 1/8 inch (3 mm) on the slope of the HMA edge. The rubberized asphalt tack coat need not be applied on the entire taper. It is considered adequate to apply it on the vertical notch and the top 3-4 inches (76-102 mm) wide band of the taper.

The rubberized asphalt sealant material is supplied as a ready to use solid material in containers. It is melted in a jacketed double boiler type melting unit, which is equipped with both agitation and re-circulation systems. The melting unit must be capable of safely heating the sealant to 400^0F (204^0C). The sealant is best applied using a pressure feed wand. Application excesses should not exceed more than ½ inch (13 mm) at the top of the joint. The sealant should preferably be applied within four hours of the time that the adjacent HMA lane is placed.

After the rubberized asphalt tack coat is applied, the adjacent lane (hot lane) is placed. The height of the uncompacted HMA should be about 1¼ inch (32 mm) for each one inch (25 mm) of the compacted lift thickness in the cold lane.

The end gate of the paver should extend over the top surface of the previously placed HMA by a distance of approximately 1 to 1½ inches (25 to 38 mm). The most efficient joint compaction method is to roll the longitudinal joint from the hot side overlapping the cold lane by approximately 6 inches (150 mm). The steel wheel roller can be operated in vibratory or static mode, preferably the vibratory mode to obtain better compaction. Compact the longitudinal joint promptly so that the minimum density at the joint is 91 percent of the theoretical maximum density (TMD), that is, no more than 9 percent air voids at the joint. Obtain a minimum mat density (away from the joint) of 93 percent of the TMD, that is no more than 7 percent air voids.

The joint density is best measured by obtaining a 6 inch- (150 mm-) diameter core centered on top of the visible line between the two lanes.

2. Rubberized Asphalt Tack Coat and Minimum Joint Density Requirements.

This practice is similar to that in Item 1 above except that no notched wedge joint is used. The first lane (cold lane) is paved as usual with the normal, unconfined edge slope. A rubberized asphalt tack coat is applied on the entire face of the unconfined edge of the cold lane using the procedure described in Item 1. Best practices for paving and compacting the first lane, paving the second lane and overlapping, raking and luting, and compacting the longitudinal joint should be followed as given in Item 1. The minimum joint density and mat density requirements should also be same as Item 1.

3. Notched Wedge Joint and Minimum Joint Density Requirements.

This practice is similar to that in Item 1 above except that a conventional tack coat material (which is used on the main line) is applied to the entire face of the notched wedge joint in lieu of rubberized asphalt material. Best practices for paving and compacting the first lane, paving the second lane and overlapping, raking and luting, and compacting the longitudinal joint should be followed as given in Item 1. The minimum joint density and mat density requirements should also be same as Item 1.

4. Cutting Wheel and Minimum Joint Density Requirements.

The cutting wheel technique involves cutting 1½ - 2 inches (38-51 mm) of the unconfined, low-density edge of the first paved lane after compaction, while the mix is plastic. The cutting wheel is usually 10 inches (254 mm) in diameter with the cutting angle about 10 degrees from the vertical towards the mat to be cut and about 45 degrees on the open side to push the trimmings away. The cutting wheel can be mounted on an intermediate roller or a motor grader. The HMA trimmings can be collected and recycled. This process obtains a reasonably vertical face at the edge, which is then tack coated before placing the abutting HMA. It is important to restrict the overlap to about ½ inch (13 mm) while placing the adjacent lane, and to remove all low-density material at the edge of the first paved lane. Some contractors remove as much as a 3-inch (75- mm) strip to meet and exceed joint density requirements. It is very important to have a skilled cutting wheel operator, who must cut straight without wavering and a skilled paver operator, who must closely match the cut line with minimal overlap. Best practices for paving and compacting the first lane, paving the second lane and overlapping, raking and luting, and compacting the longitudinal joint, and minimum joint density and mat density requirements should be followed as given in Item 1.

It is believed the preceding four recommended practices will produce reasonably durable longitudinal joints in airfield pavements.

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